FLEXIBLE IMAGE SEGMENTATION AND QUALITY ASSESSMENT FOR REAL-TIME IRIS RECOGNITION

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ABSTRACT

The human iris has proved to be one of the most reliable biometric features for the identification of individuals. Real-time iris recognition requires high quality images that provide enough details about the iris texture and algorithms to analyze and process the images at the highest possible speed.

In this work, an extension to the classical circular model for the pupil and iris using flexible contours is provided. Then, a method for assessing the quality of the iris images in real-time based on the segmentation results is introduced. Experimental results are presented, and we conclude that the new methods improve the recognition rate, achieving a 100% correct recognition rate on the CASIA iris database, while being suitable for a real-time iris recognition camera system.

***Index Terms*—** image segmentation, real time systems, image edge analysis

1. INTRODUCTION

The human iris has a complex pattern and it is supposed to be one of the richest biometric features. Since the iris is an external and visible part of the eye, an image of the iris contains enough information for the identification of a person with very low error rates. This fact allows to build an automatic, video-based system for identification of individuals via iris recognition.

The basis of iris recognition were proposed by Daugman [1]. The process can be divided in three main stages: first, a good quality image must be *captured*, then the image must be *segmented* to properly locate the iris texture, and finally the iris texture must be *encoded* for performing the recognition.

This work deals with the capture and segmentation stages of the process, and it is organized as follows: in section 2 the classical segmentation algorithm based on circle detection is analyzed, an extension to this model using flexible contours is introduced and an original iris segmentation algorithm is presented. In section 3, a new method for assessing the quality of the iris images based on the results of the segmentation stage is introduced. Experimental results are presented in section 4, and the conclusions of our work are drawn in section 5.

2. IRIS IMAGE SEGMENTATION

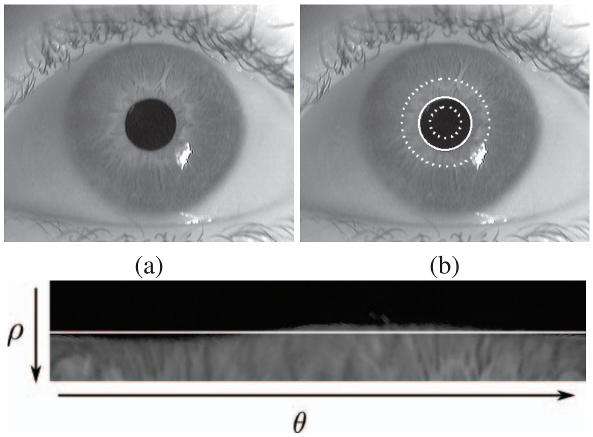
In order to locate the iris and the pupil in the image, it is needed to use some kind of model to represent both. The classical method, proposed initially by Daugman [1], uses circles to model both the pupil and the iris, while more refined methods may use ellipses instead of circles [2]. Both methods have some disadvantages: the circular model is limited and it may not fit the real shape of the iris or the pupil, or it may present serious problems when images are captured with affine distortions. The elliptic model, while more accurate, requires much more processing time since it needs to search the parameters on a 5-dimensional space.

Only recent works have proposed modeling the iris and pupil using more flexible methods like snakes [3] and active contours [4, 5]. In this work, we introduce an extension to the circular model that allows to represent the iris and the pupil using flexible contours based on the derivative of the image in the radial direction.

We propose a three-step segmentation process: first, approximate the contour of the pupil using a circular model, then adjust the contour of the pupil and finally search for the contour of the iris.

2.1. Segmenting the pupil

Under infrared illumination, the pupil is usually by far the darkest feature of the image. Since the iris is located around the pupil, it makes sense to begin the segmentation stage by locating the pupil, at least approximately. The circular model mentioned above provides a good approximation to the contour of the pupil. This model is simple enough so that a fast segmentation algorithm that searches for the circle's parameters can be implemented. In this case, we implemented an optimized integro-differential operator [1] that uses only integer arithmetic, using a modified version of Bresenham's circle-drawing algorithm [6]. This method proved to be extremely fast and give good approximations to the contour of the pupil.



(a) (b)

(c)

Fig. 1. (a) A typical image as captured by an infrared iris camera system. (b) Segmentation using a circle detection algorithm (solid line) and the ring of the image to extract (dotted line). (c) Unwrapped ring, represented in polar coordinates, where the detected circle becomes a straight line and the border of the pupil becomes a curve close to this line.

2.2. Adjusting the contour of the pupil

While the circle is an *approximate* model, the pupil may present a slight deviation from a circular shape. If these deviations are not considered, part of the pupil could be identified as part of the iris texture, which could affect the resulting iris code and degrade the system's performance.

To overcome this problem, we allow the circular contour to be deformed along the radial direction according to the image's derivative in that direction using a method inspired by [3]. We extract a ring of the image around the circular contour that we have found and we "unwrap" it representing the ring's points in polar coordinates (Fig. 1). This operation is formally defined by the following formula:

$$R(\theta, \rho) = I(x_p + \rho \cdot \cos\theta, y_p + \rho \cdot \sin\theta) \tag{1}$$

where R is the ring representation in polar coordinates, I is the image to process, x_p and y_p are the coordinates for the center of the pupil, $\theta \in [0, 2\pi)$ and $\rho \in [r_{\min}, r_{\max}]$. $r_{\min}$ and $r_{\max}$ must be chosen so that $r_{\min} < r_p < r_{\max}$ (where r_p is the radius of the pupil).

Under this representation, the circle we found in the previous step becomes a horizontal line while the contour of the pupil becomes a curve that closely follows this line. Since the iris and the pupil have good contrast under infrared illumination, it is expected that the derivative of R in the vertical (radial) direction will be maximum on the border between the iris and the pupil, that is, the contour of the pupil. Then, we define the contour $\mathcal{P}$ for each angle θ as:

$$\mathcal{P}(\theta) = \arg\max_{\rho} \left| \frac{\partial R}{\partial \rho}(\theta, \rho) \right| \tag{2}$$

The resulting contour may not be smooth or continuous: it may present gaps or outlier points caused by random noise or reflections in the eye. To make the contour smooth and continuous at the same time, we analyze the discrete Fourier transform of $\mathcal{P}$, $\mathcal{F}\{\mathcal{P}\}$. Since most of the curve is already smooth and continuous (except for a few points), we expect that a few coefficients of $\mathcal{F}\{\mathcal{P}\}$ will represent the shape of the curve without being affected by noise. So, we define $\mathcal{F}_n\{\mathcal{P}\}$ as:

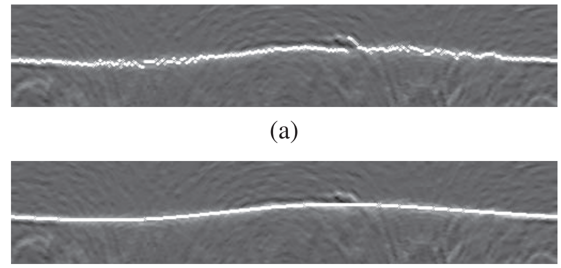
$$(\mathcal{F}_n\{\mathcal{P}\})_i = \begin{cases} (\mathcal{F}\{\mathcal{P}\})_i & \text{if } |i| \leq \frac{n}{2} \\ 0 & \text{if } |i| > \frac{n}{2} \end{cases} \tag{3}$$

where i represents the i-th Fourier coefficient of $\mathcal{F}\{\mathcal{P}\}$ and n the number of coefficients to use (the rest of the coefficients are set to zero). Using very few coefficients yields good results, since we expect the contour to be very smooth (Fig. 2).

Finally, the smooth contour, $\mathcal{P}_S$, expressed in polar coordinates, is given by:

$$\mathcal{P}_S = \mathcal{F}^{-1}\{\mathcal{F}_n\{\mathcal{P}\}\} \tag{4}$$

We convert $\mathcal{P}_S$ back to the image coordinates by performing the inverse of the operation described in Eq. 1.



(a)

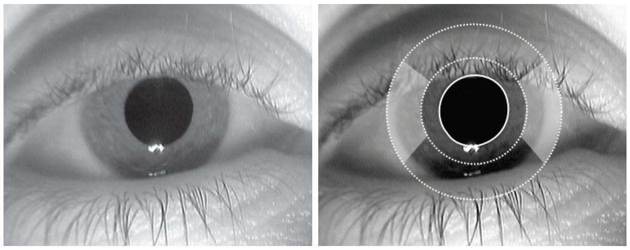
(b)

Fig. 2. Adjusting the contour in polar coordinates: (a) The maximum of the derivative of the ring in the radial direction. The resulting contour is not smooth. (b) Smoothed contour using the first 5 Fourier coefficients.

2.3. Segmenting the iris

Once the pupil is correctly located in the image, the iris is relatively easy to locate since it is almost concentric to the pupil. However, there are two problems that make using a circle detector harder:

1. The iris may be obstructed on the upper and the lower part by the eyelids.
2. The contrast between the iris and the sclera is not as good as the contrast between the pupil and the iris.



(a) (b)

Fig. 3. (a) An iris image with obstruction by eyelids. (b) Region of interest for segmenting the iris where the eyelids are less likely to occur.

Fig. 4. Horizontal lines in both regions where the derivative is maximized. These closely correspond to the contour of the iris.

To overcome these problems, we developed an original iris segmentation algorithm based on the idea presented on the previous step. We start again extracting a ring S centered on the pupil and converting it to polar coordinates, but this time the ring lies outside the boundaries of the pupil. The ring must include the portion of the image where the iris border is more certain to be located (we found empirically that the radius of the iris is between 1.3 and 5 times the radius of the pupil).

Once the ring is unwrapped into polar coordinates, the contour of the iris becomes mostly a horizontal line, however, it may present some degree of obstruction by the eyelids. This problem is solved by analyzing only the regions of the ring where the obstruction is less likely to occur. These regions are the left and right quarter of the ring, since the obstruction usually occurs at the top (by the upper eyelid) and the bottom (by the lower eyelid) (Fig. 3).

The border of the iris must then be searched for in these two regions. Since the border is almost a horizontal line in polar coordinates that divides the iris texture from the sclera, it is found by maximizing the energy of the derivative across all the horizontal lines in both regions. We define ρ_1 and ρ_2 as the lines where the energy of the derivative is maximum in each region, respectively (Fig. 4):

$$\rho_1 = \arg\max_{\rho} \int_{-\frac{\pi}{4}}^{\frac{\pi}{4}} \left(\frac{\partial S}{\partial r}(\theta, \rho) \right)^2 \mathrm{d}\theta \tag{5}$$

$$\rho_2 = \arg\max_{\rho} \int_{\frac{3}{4}\pi}^{\frac{5}{4}\pi} \left(\frac{\partial S}{\partial r}(\theta, \rho) \right)^2 \mathrm{d}\theta \tag{6}$$

If the pupil is perfectly centered on the iris, it will happen that $\rho_1 = \rho_2$, however, this is not usually the case. So, a linear interpolation between the two lines is performed and the contour of the iris, $\mathcal{I}$, is constructed on the polar coordinates space:

$$\mathcal{I}(\theta) = \begin{cases} \rho_1 & \text{if } \theta \in [-\frac{\pi}{4}, \frac{\pi}{4}] \\ \rho_1 + \frac{\theta - \frac{\pi}{4}}{\pi/2}(\rho_2 - \rho_1) & \text{if } \theta \in (\frac{\pi}{4}, \frac{3}{4}\pi) \\ \rho_2 & \text{if } \theta \in [\frac{3}{4}\pi, \frac{5}{4}\pi] \\ \rho_2 + \frac{\theta - \frac{5}{4}\pi}{\pi/2}(\rho_1 - \rho_2) & \text{if } \theta \in (\frac{5}{4}\pi, \frac{7}{4}\pi) \end{cases} \tag{7}$$

The contour $\mathcal{I}$ is an approximation of the contour of the iris in polar coordinates using only four line segments. Since a smooth contour is also expected, $\mathcal{I}$ is further smoothed using the Fourier coefficients method expressed in section 2.2.

3. ASSESSING IMAGE QUALITY

Real-time iris recognition requires analyzing a stream of video captured by a camera and it needs to decide when an optimum image for recognition is captured.

Usually the quality of the images is checked prior to the segmentation stage by analyzing the high frequencies of the image, with the idea that an image that is *in focus* will present a strong response at the higher frequencies [7, 8, 9]. However, this has one disadvantage: it may assume an iris image is in focus when in fact only the eyelids are focused, since the eyelids appear as high-frequency features of the image.

Having a segmentation algorithm like the one proposed, that is able to process images in real-time, it is possible to assess the quality of the image by using the information extracted on the segmentation stage, thus relying only on the particular structure of the human eye instead of global characteristics of the image. This way, the quality assessment stage is performed *after* the segmentation stage, in opposition to the traditional method of first checking the quality and then segmenting the image.

We propose to use the level of contrast between the border of the pupil and the iris for assessing the image focus, assuming that a well-focused image will present a strong contrast in this area. Given the ring R as defined in Eq. 1 and the contour of the pupil in polar coordinates $\mathcal{P}_S(\theta)$ as defined in Eq. 4, we measure the contrast q as:

$$q = \frac{\int_0^{2\pi} \int_{\mathcal{P}_S(\theta)-\Delta\rho/2}^{\mathcal{P}_S(\theta)+\Delta\rho/2} \left(\frac{\partial R}{\partial \rho}(\theta, \rho) \right)^2 \mathrm{d}\rho \, \mathrm{d}\theta}{\iint \left(\frac{\partial R}{\partial \rho}(\theta, \rho) \right)^2 \mathrm{d}\rho \, \mathrm{d}\theta} \tag{8}$$

where $0 \leq q \leq 1$.

That is, q measures the power of the derivative across a strip of width $\Delta\rho$ centered on the contour of the pupil, with respect to the total power of the derivative in R (Fig. 5). Experimentally, we found that values of $q \geq 0.6$ give as result images with good enough quality for recognition.

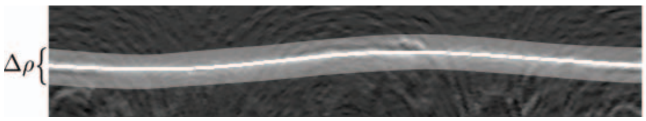


Fig. 5. A strip centered on the contour of the pupil is used to measure the quality of the image. The width of the strip is defined by the parameter $\Delta\rho$.

4. RESULTS

In order to test the flexibility, speed and performance of the proposed segmentation algorithm, we used the freely available CASIA and MMU [10] iris databases. The segmentation algorithm was implemented in C++. It takes an average of about 35 milliseconds to segment each individual image on a 1.3 GHz Pentium processor, so the algorithm is able to analyze about 28 images per second, which is suitable for a real-time system. A total of 97.5% of the 756 images found on the CASIA iris database were segmented correctly, as were 98.2% of the 450 images found on the MMU iris database, so the algorithm is flexible enough to provide good segmentation results in two different databases.

We measured the impact of the improved segmentation algorithm through the *decidability*, which is a dimentionless value that measures how well separated the distributions of Hamming distances between intra-class (same eye) and inter-class (different eyes) comparations are [7]. The decidability d' is defined as:

$$d' = \frac{|\mu_{\text{inter}} - \mu_{\text{intra}}|}{\sqrt{\frac{\sigma^2_{\text{inter}} + \sigma^2_{\text{intra}}}{2}}} \tag{9}$$

where μ_{intra} and σ_{intra} are the mean and the standard deviation of the Hamming distance of intra-class comparisions respectively. μ_{inter} and σ_{inter} represent the same values for inter-class comparisions.

In order to calculate the decidability value, we created iris codes using 1D Log-Gabor filters as explained in [11].

In the CASIA iris database, the traditional circular model gave us a decidability value of 6.61 with a correct recognition rate of 99.94% between the correctly segmented images. Under the flexible contour model proposed in this paper, we achieved a decidability value of 7.22 with a 100% correct recognition rate, that is, no two images were incorrectly classified. These improvements are directly related to the fact that the flexible contours model introduced in this work provide a better approximation to the shapes of the pupil and the iris.

5. CONCLUSIONS

In this work we introduced an improvement to the traditional circular model for the pupil segmentation stage through the use of flexible contours and we proposed a new iris segmentation algorithm. The new method proved to be very fast and suitable for a real-time implementation. At the same time, it improved the recognition results, allowing a 100% correct recognition rate on the CASIA database and a greater separation between the intra-class and inter-class Hamming distances.

We also proposed a new method to assess the quality of an iris image based on the segmentation results. This method is used to select the best possible image on a video stream as captured by an iris camera system.

The segmentation algorithm was incorporated to an iris recognition camera system developed by ourselves. Together with the quality assessment method introduced in section 3, we were able to build a real-time iris recognition system which is able to capture high-quality images and requires minimum interaction.

6. REFERENCES

[1] J. Daugman, "High confidence visual recognition of persons by a test of statistical independence," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 15, no. 11, pp. 1148–1161, November 1993.

[2] K. Miyazawa, K. Ito, and T. Aoki, "An efficient iris recognition algorithm using phase-based image matching," Tech. Rep., Graduate School of Information Sciences, Tohoku University, 2005.

[3] J. Daugman, "New methods in iris recognition," *IEEE Transactions on Systems, Man and Cybernetics*, vol. 37, no. 5, pp. 1167–1175, October 2007.

[4] E. Arvacheh and H. Tizoosh, "Iris segmentation: Detecting pupil, limbus and eyelids," *IEEE International Conference on Image Processing*, pp. 2453–2456, October 2006.

[5] Z. He, T. Tan, and Z. Sun, "Iris localization via pulling and pushing," *18th International Conference on Pattern Recognition*, pp. 366–369, 2006.

[6] J. D. Foley and Andries van Dam, *Computer Graphics: principles and practice*, Addison-Wesley, 2nd edition, 1990.

[7] J. Daugman, "How iris recognition works," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 14, no. 1, pp. 21–30, January 2004.

[8] Y. He, Y. Cui, T. Tan, and Y. Wang, "Key techniques and methods for imaging iris in focus," in *The 18th International Conference on Pattern Recognition (ICPR'06)*, 2006, number 0-7695-2521-0.

[9] B. J. Kang and K. R. Park, "Real-time image restoration for iris recognition systems," *IEEE Transactions on Systems, Man and Cybernetics*, vol. 37, no. 6, pp. 1555–1566, December 2007.

[10] P. S. Lee and H. T. Ewe, "Individual recognition based on human iris using fractal dimension approach," *Lecture Notes in Computer Science*, vol. 3072, pp. 467–474, 2004.

[11] L. Masek, "Recognition of human iris patterns for biometric identification," M.S. thesis, School of Computer Science and Software Engineering, University of Western Australia, 2003.